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MODELING CITIES
The Los Alamos Urban Security Initiative

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The vulnerability of urban populations to crises, poor urban decision making, or terrorism means that city stability is a national security issue. And as cities continue to grow, their components are becoming increasingly intertwined, forcing public works officials to treat urban systems as a "system of systems." The Urban Security Initiative is an integrated, science-based approach that will link computer models of a range of urban processes so that managers can better understand urban interdependencies, make realistic predictions of city vulnerability and sustainability, and improve planning and management. Several pilot studies are also focusing on urban issues where environment, infrastructure, and society are linked, including (a) transportation and toxic plumes crises; (b) earthquake damage to infrastructure and city regrowth after such disasters; (c) pollution's effects on airborne transport of particulates and their eventual fate in surface water and groundwater; and (d) a novel, computer-based technique for obtaining consensus on difficult urban issues with large numbers of stakeholders.

Within the near future, the bulk of the earth's human population will reside in cities (Fuchs, 1994). And all cities regardless of size have similar sets of interrelated problems associated with safety, sustainability, growth, energy distribution and usage, water supply, transportation, food and goods distribution, microeconomics and regional economics, the environment, and the quality of life. An understanding of the relationships between the components making up the urban system allows us to better evaluate vulnerabilities related to natural hazards such as a hurricane or an unnatural event such as a terrorist attack. And because cities are places in which infrastructure elements converge and environmental problems can easily become acute,

the same linked systems must also be understood in order to plan sustainable urban environments. The stability of the United States and the international community will depend to a large extent on the vitality of our cities. This is the reason we call our initiative Urban Security, and why Los Alamos, a national security laboratory, is focusing on the topic.

Understanding urban systems demands multidisciplinary approaches that account for physical processes, economic and social factors, and nonlinear feedback[1] across a broad range of time and space scales. The Los Alamos Urban Security Team includes environmental engineers, geologists, software designers, natural hazard specialists, urban planners, mathematicians, hydrologists, physicists, civil and electrical engineers, atmospheric scientists, chemists, geographic information system specialists, and transportation experts who work in collaboration with urban planners and environmental scientists from academia and the government. Strong research programs in the defense, environmental, and computational arenas at the Los Alamos National Laboratory have developed many state-of-the-art computer models[2] for individual components of urban modeling systems. These include programs in transportation, air quality, groundwater transport, energy distribution, communications, synthetic population modeling,[3] natural hazards, and risk assessment. We are building on these and other modeling tools and linking them together as a simulation system that can take advantage of today's commonly available PCs and work stations as well as high-performance computing platforms. We are engaging collaborators from the urban planning community and university campuses to ensure relevance and eliminate "wheel reinventing."

The Urban Security Initiative is relatively new and proceeding along two fronts. One is the development of an overall approach that will enable straightforward integration of the wide range of processes and considerations that come into play in urban systems. The other is a series of pilot studies on specific problems, where integration of natural and human-made systems is key. This article presents some of our work to date and provides an indication of future research needs. Topics covered include the following:

- A computing framework prorotype that allows computer models of urban components to produce simulations on a variety of different machines and in different computer languages and exchange data via a geographic information system (GIS);[4]
- Pilot studies on vulnerability to human-made (e.g., toxic gas plumes) and natural disasters (e.g., earthquakes) in which we link environmental and infrastructure models;
- Modeling of the regrowth of an urban center after a major disaster, and how such modeling can be a useful tool to aid in planning for such scenarios;
- The early phases of research on the links between air pollution and surface water and storm drain water quality, (this research is an example of the importance of linking infrastructure and environmental considerations for sustainable development);
- Some of the important contributions and issues surrounding the GIS in urban systems;
- A novel, computer-based concept for achieving consensus among large numbers of stakeholders for difficult decisions with regard to urban planning.

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Urban Security Modeling Architecture

OVERVIEW

For computer modelers, an architecture is like a blueprint for setting up models and relating them to each other. Our Urban Security architecture is illustrated in Figure 1. On the right-hand side of the diagram, we have examples of the basic components of an urban system. Computer models are available or can be developed for each of these components (and others that are not shown); our focus is on linking the component models. This is done through interface physics modules that describe the relationships between components. For example, if an atmospheric model predicts a certain amount of rainfall within 1 hour, the interface physics module would predict how much runoff would result, which would in turn be used to predict the flow in rainwater drainage systems. In another example, an interface physics module would use predicted ground motion from an earthquake model to determine level of damage to individual substations, which would then be used in a model of the response and recovery of the urban electrical power grid as a whole. In our architecture, the right-hand side provides the scientific basis for modeling the urban system or components of it.

The middle portion of the architecture takes the results of the detailed component models and turns them into something useful for planners and decision makers. Part of this is a process we call abstraction, which simplifies results of large-scale calculations so that the overall behaviors can be readily understood. For example, if we are interested in the impact on regional air quality of a new transportation system on the outskirts of a city, we might do a series of detailed component calculations, each one representing a possible combination of parameters. Such parameters would include the season of the year, wind direction, a particular layout of the new roads, and an estimate of the possible traffic load on those roads. Accounting for all reasonable combinations of those parameters will result in a large set of complex model results. These model results may be difficult to interpret at the individual level, let alone as a whole set. Furthermore, the details of the calculations do not necessarily need to be understood; what is of interest is simply the probability that a new transportation system will cause air quality to be below some standard. The abstraction process takes the complicated component calculations and boils them down to answer the question at hand. Statistical methods come into play in abstracting the large calculations. Neural networks is one specific mathematical technique, modeled after the human brain, which can look at a set of complicated calculations and find patterns or important results. Another form of abstraction is to use highly simplified models of individual urban components in the first place; a decision to take this route depends on the modeling tools needed to address a specific issue.

Servers are part of the interface between component models and end users. A server in our architecture is a computer or group of computers that provides information to other computers that actually do various types of calculations. Because it makes sense to treat most urban problems in a spatial sense (in other words, in terms of location on a map, depth below the ground, or height above it), the GIS must play a central role. The GIS serves as the framework for collecting, managing, and storing data such as land use, structure types, distribution systems, precipitation, and groundwater depth. A second role for the GIS that is growing in importance is as a framework for storing and managing the results of computer predictions. This facilitates the direct comparison between predictions and what is really observed. Computer modeling of most physical processes (e.g., groundwater flow, air pollution migration) requires that one break the area of interest down into a grid. The mathematical equations that describe the processes are tracked on that grid. Our architecture includes a server that makes and provides grids for component models. Finally, computer visualization is essential for understanding and interpreting results, whether they are represented by a simple graph or as a complexly shaped plume of air pollution migrating around buildings.

There are a growing number of software tools available to help aid in decision making; these form the toolkit portion of the Urban Security architecture. Tools include (a) risk assessment models, which account for the likelihood of an event and the event's consequences; (b)

Tools include (a) risk assessment models, which account for the likelihood of an event and the event's consequences; (b) decision-making tools, which allow one to weigh one planning option against several others; and (c) economic tools, which provide cost-benefit information.

Figure 1: Schematic of proposed system architecture for answering urban security questions. Sophisticated numerical models from across disciplines and covering a broad range of scales are integrated through interface physics modules. Methods for abstracting the essential physics are used to speed computations and generalize results. Links between the physics-based models are made to decision-making tools. Servers provide data and visualization tools to the end user.

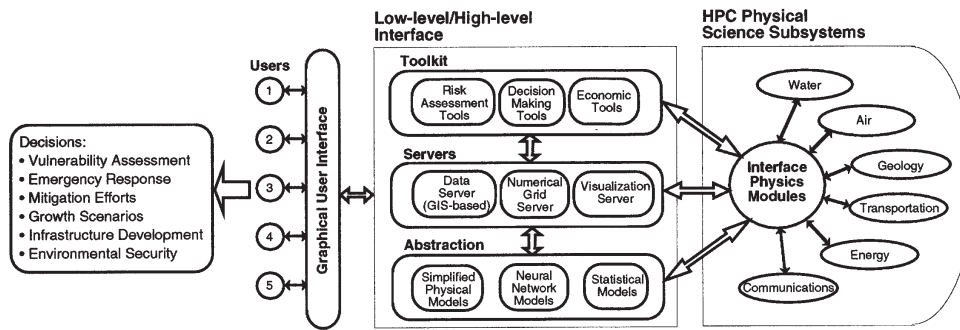decision-making tools, which allow one to weigh one planning option against several others; and (c) economic tools, which provide cost-benefit information. A new tool that we are developing uses the World Wide Web as a platform for developing consensus and decision support for difficult planning issues that affect a large number of stakeholders. All of these tools can use the science-based component modeling that is the foundation of our architecture, and users can tailor them to emphasize issues of particular importance to their urban situations.

Finally, we have understood from the start that no matter how sophisticated a computer modeling system, it will not be used unless it is easily accessible by a range of people. A very important part of our architecture is a user interface that is easy to use whether one is a scientist or a decision maker.

CURRENT STATUS

The Urban Security computing architecture is being implemented as a software framework in an Internet environment using JAVA[5] and CORBA.[6] This combination allows communication between computer models written in different computing languages and running on different machines (simultaneously if appropriate). Multiple users can log on and run the system at the same time, and security issues have been worked out to ensure that users cannot (intentionally or otherwise) affect each other's work. Perhaps the most important feature is that the system is user friendly and operated by a familiar point-and-click interface that allows for different levels of expertise. It is easy to add new models or software tools to the framework or remove old ones. The fact that a range of computer languages are supported means that old software, which may still be quite useful but is not written in modern programming languages, can be easily plugged in.

The framework consists of a setup server, application servers, and clients. The end user accesses the framework through the client by bringing up a browser (e.g., Netscape) and connecting with the Urban Security Web page. This screen lists the available system objects (e.g. database access, grid generation, visualization, and urban component models). To run a simulation, a user might first access the setup server and request setup specifications from the run-history database. The user selects the specific simulation, modifies the input, and clicks the "run" button, and the simulation executes on the remote application server. Upon completion, the client may ask the setup server to store this simulation's setup specification and run results in the run-history database, activate the visualization server, or perform some other action. We are currently in the process of testing the framework with a variety of plugged-in urban component codes and GISs. As our research progresses and the user base grows, a broad range of computer models and software tools should become available in this easy-to-use framework.
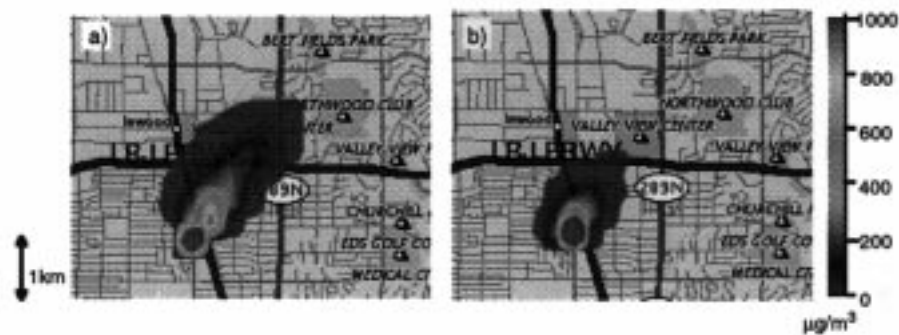
Figure 2:   Comparison of dispersion models for a contaminant cloud with: (a) HOTMAC-RAPTAD and GAS-FLOW modeling systems and (b) with the HOTMAC-RAPTAD modeling system only. The comparison demonstrates that plume dispersion is significantly affected by air flow around buildings.

Vulnerability Pilot Studies

AIRBORNE TOXIC RELEASE AND VEHICLE EXPOSURE

Emergency response and traffic issues resulting from accidental or premeditated airborne toxic releases in an urban setting were analyzed in this work. Atmospheric and vehicle transportation simulations were used to study the movement of a plume in an urban setting and the resulting exposure to vehicles being driven through the plume (Brown, Muller, & Stretz, 1997). At the time we conducted this study, the Los Alamos TRANSIMS[7] team was focusing on the transportation system of the Dallas–Forth Worth metropolitan area; because of this, we decided to study a hypothetical scenario in this area. The HOTMAC[8] mesoscale atmospheric model was used to simulate the weather and winds over several hundred square kilometers centered on Dallas. A gas source was located at ground level between the two buildings, and the near-source transport and dispersion of the contaminant cloud was simulated using GASFLOW[9] software.

To evaluate the impact of the buildings on the larger scale plume motion and spread, one simulation accounted for the buildings and one did not. We found what we considered a counterintuitive result: The plume traveled farther in the same amount of time when the influence of buildings was considered (see Figure 2). Initially, we had incorrectly guessed that the plume would travel a shorter distance in the presence of buildings because of trapping of the plume between the buildings. Although trapping does occur, a stronger process happened: The swirling air between buildings raised parts of the plume high above the ground. At these higher levels, this part of the plume could be blown rapidly downwind by the stronger winds residing there.

The transportation simulation team used the TRANSIMS model (e.g., Rickert & Nagel, 1997) to simulate traffic flow for over 100,000 vehicles in north Dallas. TRANSIMS models traffic by simulating the second-by-second movement of individual cars. The interaction of the individual cars on the street network results in traffic patterns that occur in everyday traffic.

Vehicle routes and predictions of plume motion and dilution were used to estimate exposure to over 36,000 vehicles traveling through the hypothetical contaminant cloud in the Dallas–Fort Worth area (Figure 3a). The vehicle exposure plot shown in Figure 3b clearly delineates the major thoroughfares (the North Dallas Tollway and the LBJ Freeway) and show that the contaminated vehicles carry the toxic agent away from the source location faster than do the winds. The exposed drivers end up spread over a much larger area than that covered by the plume. Moreover, the final locations of vehicles with high exposure are not obvious unless one considers the results of a simulation scenario.

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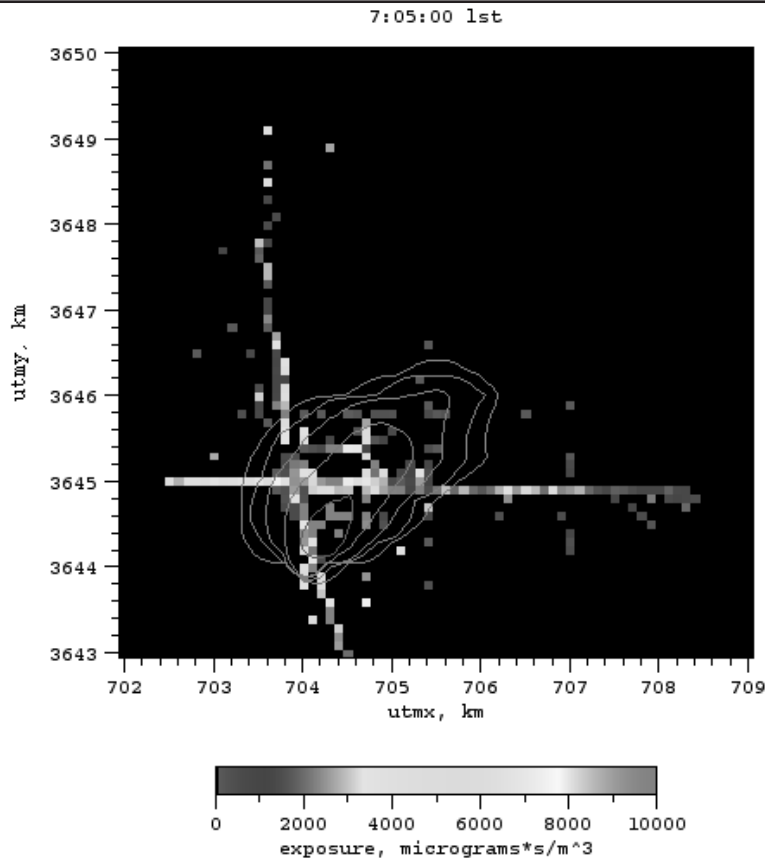
Figure 3a: Exposure levels of vehicles 5 minutes after the release start time. The gray contours indicate the location of the toxic plume at ground level.

Using a simulation tool such as this, emergency response personnel could determine the impact zones, the optimal routes for response teams, places where casualties might occur, and how the agent is dispersed. The efforts of clean-up crews and medical teams could be enhanced as well with knowledge of the final location and levels of exposure. Further research efforts are under way at Los Alamos to refine the estimates of the effects of multiple buildings on the behavior of a toxic plume. The continuing research on transportation simulation will include efforts to abstract fundamental vehicle behaviors so that simulations can be run on PCs.

EARTHQUAKES AND URBAN INFRASTRUCTURE

We are working to provide a set of science- and technology-based simulation tools for disaster planning, training, and management in times of crisis and long-term recovery after an earthquake. Coupled simulation tools simulate the operation of inter-linked infrastructure systems during and following an earthquake (Figure 4). As a first step toward creation of this coupled system, we are simulating the effects of a major earthquake on the electric distribution system in the Los Angeles Basin. This set of tools has a computer-based, multilayered GIS database coupled to software that simulates earthquake ground motions, estimates infrastructure damage, and performs analyses of functionality of the electric distribution system.

This approach was endorsed in a January 27-28, 1998, workshop with the potential end users. Attendees at the workshop included disaster response groups, the city of Los Angeles, the California state geologist, CalTrans, and the Corps of Engineers (Henyey & Andrews, 1998).

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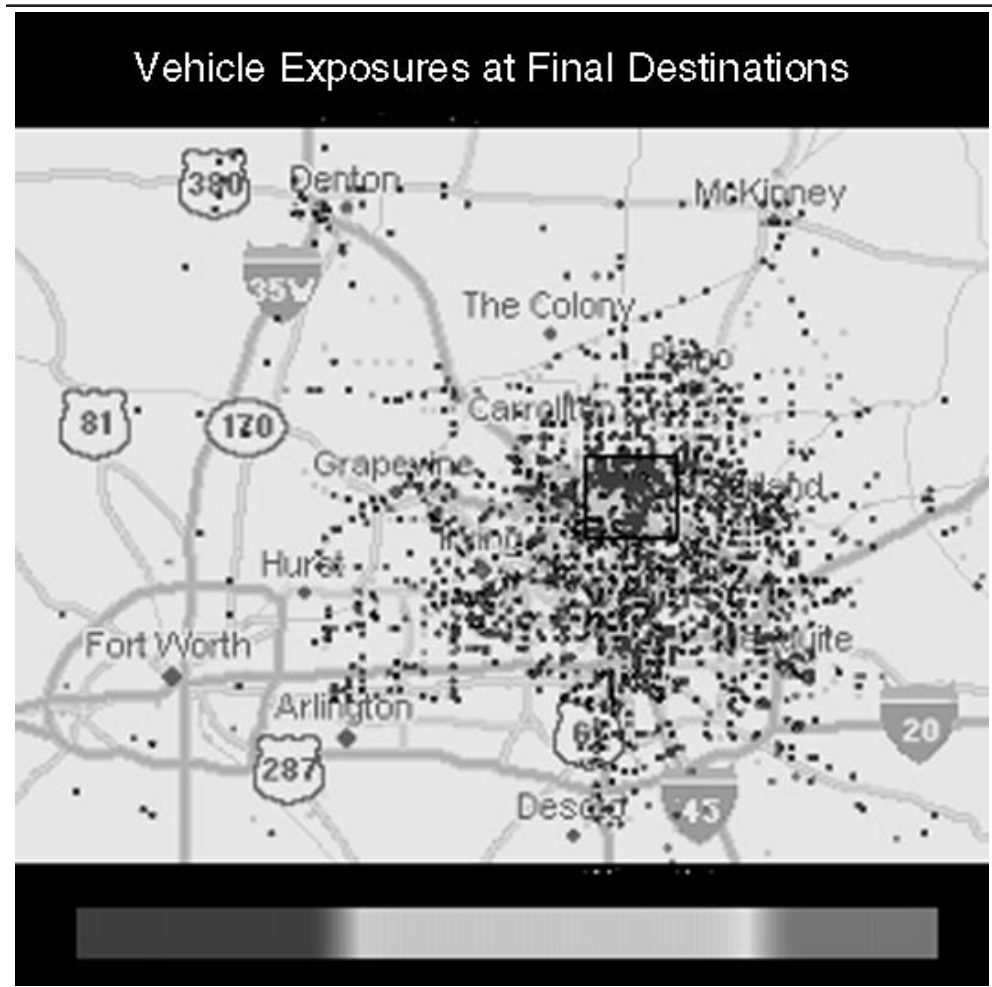
Figure 3b: Driver exposure as a function of the driver's final destination, overlain on a map of Dallas-Fort Worth. The black box denotes the area covered by the region shown in Figure 3a.

Realistic predictions of earthquake ground motions and the resulting damage requires treatment of the important physical processes that influence the location and intensity of ground motion within the urban setting.

To evaluate vulnerabilities in the electric distribution systems in Los Angeles, three earthquake scenarios are being simulated: (a) the January 17, 1994, Northridge earthquake, in which the models can be compared with what really happened; (b) an earthquake along the Elysian Hills Fault, which is close to downtown Los Angeles and would affect a high concentration of users; and (c) an earthquake along the San Andreas Fault, in which the electric distribution system that brings power into the Los Angeles Basin would be heavily damaged.

For a given earthquake, the three-dimensional propagation of seismic waves and the resultant ground motions is simulated across the Los Angeles area (Olsen & Archuleta, 1996; Olsen, Archuleta, & Matarese, 1995). Because the subsurface geology of the Los Angeles Basin is far from uniform, the intensity of the ground motions resulting from an earthquake is not be a simple function of the distance from the earthquake epicenter.

The predicted distribution of ground motions is used to estimate damage to the infrastructure. At first, the program HAZUS (Federal Emergency Management Agency, 1997) is used to make probabilistic damage estimates; but ultimately, component-specific analyses are performed to create a more plausible description of the damaged infrastructure systems. Damage to interlinked systems is also simulated. Within the damaged environment, emergency response scenarios can be modeled to aid in training and preparedness planning. In addition, various
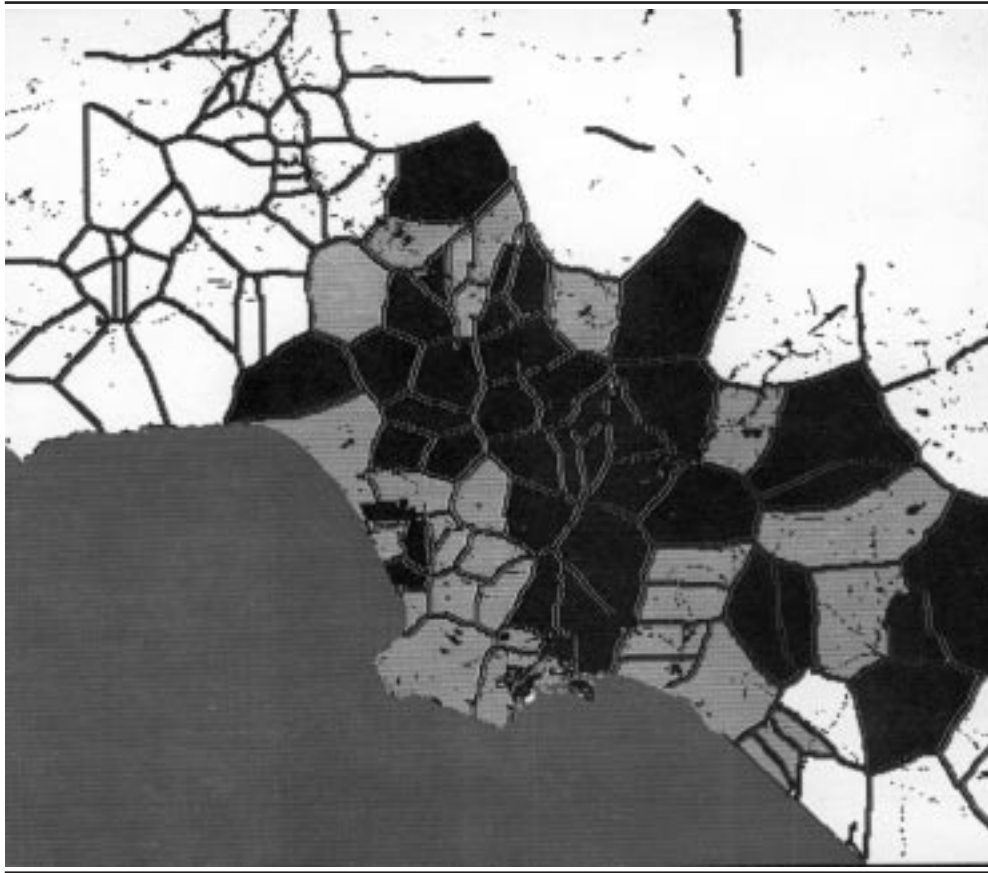
Figure 4:   Areas blacked out after a scenario earthquake on the Elysian Park fault under downtown Los Angeles. The model earthquake has a Richter scale magnitude of 6.75. This result is based on scenario earthquake ground motions for the L.A. basin, linked to an earthquake damage estimation code, which in turn is linked to information on electrical substation component fragility. Models such as these can be used to anticipate damage to infrastructure and to plan cost-efficient retrofitting. Black shows outage caused by substation failure and gray shows outage caused by isolation. The results of this model shows an estimated outage of 11, 450 MW of load. (Diagram courtesy of Jonathan Dowell)

cleanup, restoration, and recovery alternatives can be explored to facilitate the return of the damaged city to near-normal operation. Analyses of longer term rebuilding alternatives might reveal infrastructure investments that will lead to a more robust, sustainable urban system. Results of all simulations are displayed as high-quality images. This first product would be used by (a) contingency planners as a preevent planning tool; (b) responders as a real-time event-specific information source and damage assessment tool; and (c) both planners and responders to model losses, rapidly determine resources needed, and estimate social-economic impacts of both real and simulated events.

The predicted ground motions are derived from high-fidelity simulations of wave propagation done with detailed models of the subsurface geology. Because many critical components of the various urban systems are most sensitive to high-frequency ground motions—which must be simulated in very fine computational meshes—the use of high-performance computers is essential in the simulations.

CITY RECOVERY AND GROWTH:
URBAN EVOLUTION AFTER A MAJOR EARTHQUAKE

The damage in Los Angeles from a major earthquake can thus be estimated by combining the ground motions from the simulated quake with models of fragilities for buildings and other infrastructure elements as well as GIS information about land use locations. This estimate is

used as the input for a simulation of urban recovery and regrowth. We are developing collaborations with urban evolution researchers at Memorial University (White & Engelen, 1997) and the University of California, Santa Barbara (Clarke & Hooper, 1997). Our approach consists of using a newly developed, Markov random field[10] simulation for the evolution of land use in the areas partly destroyed by the earthquake. In essence, the simulation "regrows" activities or "grows" new activities for a given location depending on (a) what was there before the disaster, (b) zoning, (c) physical suitability, (d) transportation access, and (e) the land use in neighborhoods around the given location. These factors determine the potential for a given future land use (Figure 5).

The simulation takes two different kinds of input: (a) land use data, topography, and infrastructure data from the whole urban area (high resolution) and (b) regional demographic and regional economical constraints as external factors, including estimates of activity changes after a major natural disaster. This involves the collection and compilation of land use data and so on from Los Angeles as well as other places where data are available about activity changes as a result of natural disasters (Figure 5).

This regrowth simulation can address questions about the urban dynamics on a time scale from about a month to a few years. Such questions include the following: Which areas will grow again most rapidly? How sensitive are the regrowth patterns as a function of external economical and demographic factors? Which areas are least compatible with current zoning regulations, and which activities would emerge if the zoning laws were changed? Other questions of a more long-term nature (such as where the urban area is most likely to expand in the future) can also be addressed with this kind of simulation.

Sustainability Pilot Study:
Urban Air-Water Pollutant Transport Pathways

We are working toward a simulation of the transport of pollutants in an urban environment from beginning to end. To follow the pollutants through the complete air and water pathway system, we must link cross-disciplinary subsystem models and tailor them for urban applications. We are focusing on the transport and fate of nitrogen species because (a) they track pollutants through both the air and water pathways; (b) the physics, chemistry, and biology of the complete cycle are not well understood; (c) nitrates have important health, local ecosystem, and global climate implications; and (d) this problem requires us to stretch our capabilities in nontraditional areas, including several relating to urban infrastructure and security.

We are currently simulating the fate of nitrates in the Los Angeles Basin from their beginning as nitrate precursors,[11] produced by auto emissions and industrial processes. We track their movement and chemistry as they are transported by surface winds, deposit on the ground, and then trace their path as they are carried by surface water runoff to the rainwater drainage system where dilution and biologically mediated chemical reactions take place. Finally, we follow these nitrates into wetlands and coastal water bodies (Figure 6).

The system of linked models used for studying the fate of pollutants through air and water pathways is shown in Figure 7. In short, the RAMS[12] (Costigan, 1998) and HOTMAC (Brown & Williams, 1998) software provides time-dependent three-dimensional meteorological fields for the California Institute of Technology (CIT) model (air chemistry software) (Russell, Winner, Harley, McCue, & Cass, 1993). The CIT software is then to be used to simulate the gas and aerosol behavior and produce wet and dry deposition fields of various pollutants. The deposited pollutants are input to the SWMM model[13] (Huber & Dickinson, 1988) along with rainfall predictions from RAMS. SWMM computes urban runoff flow amounts and water quality, which is then used by the WASP[14] (Ambrose, Wool, & Martin, 1993) model to simulate the fate of pollutants in water bodies. Our first year's efforts have concentrated on running each of the described models, obtaining data sets needed for model input and validation, and linking the models in a crude way in order to follow the pollutants through the complete system (see Brown et al.,

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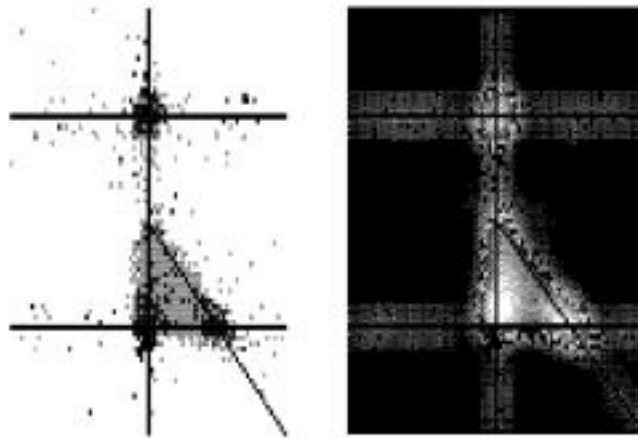
Figure 5: The left figure shows the land-use patterns (white = non-urbanized; light gray = housing; dark gray = commercial; black = industry; major roads = black) at a given time for a notional city, which has been generated in simulation. The figure on the right shows the corresponding potentials (light = high, dark = low) for commercial activities given the existing land-use pattern in first figure. Note how the most likely areas for new commercial developments coincide with large housing areas and the major roads. These same simulations can be used to predict most likely land-use patterns after a major disaster.
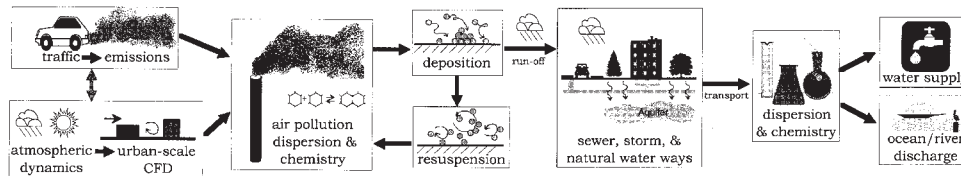

Figure 6: Nitrate pathway through the transportation, air, and water systems. The proposed modeling system can be applied to many different kinds of air contaminants (e.g., from accidental spills, industrial sources, a Chemical and Biological Weapons attack). The air/water modules could be used in reverse to track vapors emanating from underground sources, as in many EM clean-up projects.

1998). In addition, we are working with the earthquakes and urban infrastructure team to look at flood control strategies after an earthquake has damaged rainwater pipes and channels.

To complement our research efforts, we have developed collaborations with leaders in different fields, including Carnegie-Mellon University and Georgia Tech University (size-resolved particulate chemistry modeling); the University of California, Los Angeles (UCLA), Department of Civil Engineering (the runoff modeling and water quality data sets); the Los Angeles City Storm Water Bureau and Los Angeles County Public Works (rainwater data sets and end user expertise); the University of Alabama Department of Civil Engineering (rainwater modeling); and the UCLA School of Public Health (biologically mediated chemistry).

With a linked air and water modeling system, we hope to address both water and air quality issues jointly rather than separately. Often, air pollution reduction strategies are evaluated without considering the impact on water quality and vice versa. Occasionally, a reduction strategy can improve the quality of one medium but harm the other (methyl T-butyl ethylene [MTBE] fuel additives may be a case in point). For the Los Angeles Basin and coastal region, we hope to ascertain how much of the nitrate pollution comes from the atmosphere as compared to other nonatmospheric sources. An understanding of the nitrate pollution budget in the coastal region will help us choose the best strategies for improving the water quality. Finally, we wish to

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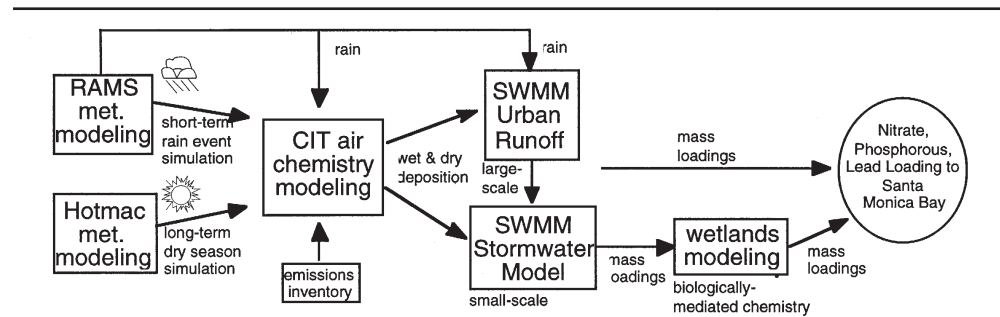
Figure 7:   Modeling systems for following pollutants through air-water pathways in an urban environment. With some modifications, the fate of pollutants from other sources could be modeled as well, for example, accidental releases of toxic agents, heavy metals from brake pads, or noxious vapors from waste sites.

evaluate the minimum number and fidelity of costly urban data sets that are needed to understand and make responsible decisions about air and water quality problems.

Role of GISs in Urban Security

GISs are important to all aspects of modeling a city and handle large and diverse data sets, as well as the basis on which most of the numerical systems models handle those data sets. A GIS can be generally defined as a database for geographic information. Thus, a GIS is a tool set for storing and manipulating spatial data. These spatial data often include tabular or relational data, so that a GIS can be thought of as a superset of relational database management systems. In the context of the Urban Security Initiative, the GIS provides two basic contributions: It serves as a means for gathering and manipulating geographic data from a variety of sources and a channel through which different urban component models and software tools can pass and share information.

Interestingly, both of these services are complicated by the same problem—a flat-earth view of the world. Nearly all geographic data are expressed in only two spatial dimensions, even though the world is not flat. The "mapping" of these data to a flat plane would be straightforward if the earth were a perfect sphere.

Unfortunately, the earth is more perfectly represented as an ellipsoid of revolution, and this choice of ellipsoid may vary between data sources depending on the region of interest for that particular source of data. While the earth is spherical to within 0.3%, the actual location "on the ground" for different assumed ellipsoids can vary by as much as 300 meters for the same real-world location. In the urban environment, where a single-lane street is only 10 meters across, the importance of the assumed spheroid is obvious. Frequently, street-level data such as rainwater-sewer networks are available from county governments, which use computer-aided design (CAD) systems. Although data from county governments may be survey quality, the coordinate system county governments use is only "internally consistent," and frequently these data are available only in hard-copy format. Thus, the process of data collection can fall somewhere between detective work and grunt work.

Physics-based models of earth processes have data needs that can be classified into static or dynamic data. Static data are data that may come from the U.S. Geological Survey, county governments, or remotely sensed (satellite or aircraft) systems. These data are accepted as given by the models for the time span of the study. The design philosophy within the Urban Security Initiative has been to use existing modeling applications rather than to make a large investment in creating new applications. Coupled modeling is implemented from the bottom up, drawing on the knowledge bases that correspond to models of different urban components. A computer

Links between physical models are designed to obey laws of conservation of mass, momentum, and energy. Furthermore, these quantities are fluxes (i.e., distributed in space and time). Thus, the problem of enforcing conservation (e.g., not creating/destroying rainwater) falls on the GIS. The GIS acts as a channel through which the various models can communicate.

model of rainwater flow, for example, accepts precipitation as a boundary condition, since the developers of a rainwater model may not have the expertise to rigorously model atmospheric processes. The rainwater model computes the concentrations of contaminants and flow rates of water in different piping systems, but would pass the necessary information to a chemistry model for computing chemical reaction rates.

Most models of earth science assume a flat earth and (like the agencies that provide static data) generally assume a coordinate system that is unique to that model. Links between physical models are designed to obey laws of conservation of mass, momentum, and energy. Furthermore, these quantities are fluxes (i.e., distributed in space and time). Thus, the problem of enforcing conservation (e.g., not creating/destroying rainwater) falls on the GIS. The GIS acts as a channel through which the various models can communicate.

Decision Support and Consensus Building Using Collective Intelligence

To be prepared for a major natural disaster is obviously a task that involves many institutions and individuals, with each institution having specific needs. To facilitate the disaster-planning process, we are currently developing a Web environment that allows multiple organizations to face collective challenges that are not approachable from the level of the individual. The Web site is set up to establish a consensus among organizations in response to a disaster—for example, how to have relief supplies strategically placed in anticipation of an earthquake.

Social animals such as ants, wolves, and humans form groups to enhance the survival of the individuals who make up those groups. We as individuals contribute and adapt to groups and societies because they make life easier in one way or another, even though we may not always understand that process (either individually or collectively). These higher order structures have properties that individuals lack. Despite little understanding of *how* a process works, societal organization has changed significantly through history, from small and separate hunting tribes to highly technological, globally integrated groups.

We can now combine this understanding of self-organizing societal dynamics with self-organization on the Internet. The unique capability of the Internet is that it combines in a common medium the breadth and depth of most human-technological systems. It integrates the heterogeneous systems of machines, information, and people and captures the complexity of information in both its creation and use. Internet committees counting thousands of individuals can reach consensus swiftly using its capability (Johnson et al., 1998; Rasmussen & Johnson, 1998).

Consensus among the many stakeholders in Los Angeles on how best to organize disaster relief for a major earthquake can be reached faster, cheaper, and more efficiently on the Internet. Assuming that all stakeholders involved in planning for such a disaster will have access to a given Web site, we propose a Web environment that consists of three parts:

1. Detailed scenario data from earthquake simulations together with damage estimates from different potential earthquakes (urban regrowth scenarios can also be available here);
2. Information about the mission, mode of operation, and so on of each of the involved stakeholders;
3. An interactive area in which each stakeholder can sort disaster-planning issues according to importance, order necessary actions in time sequences, request resources, and so on (the information given by each stakeholder organization is able to interact with other stakeholder-given information through voting and other means) (Figure 8).

A disaster-planning session using this Web tool could in principle unfold along these lines:

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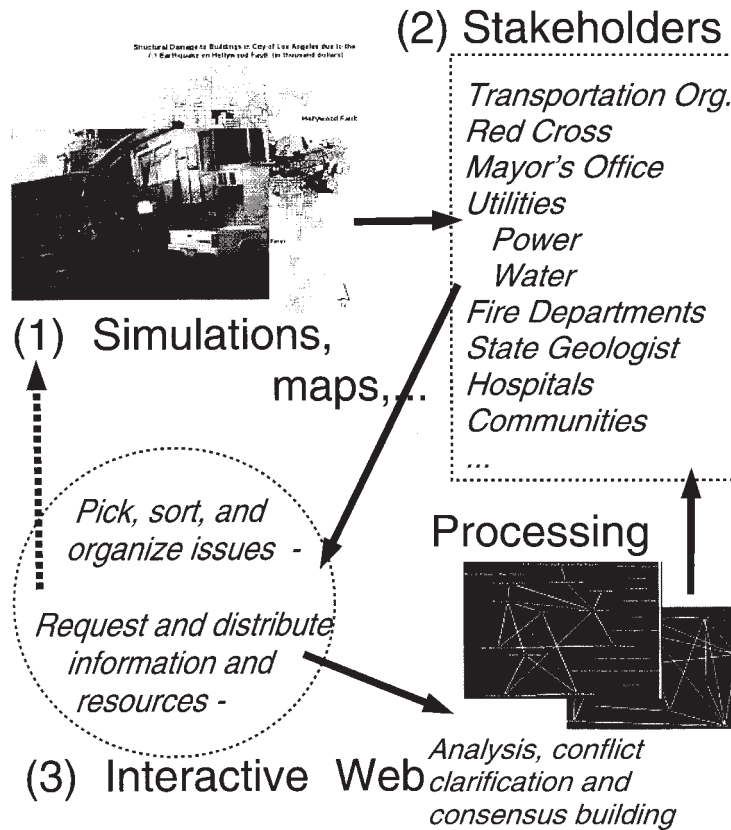
Figure 8:   Web-Based Emergency Planning

- Although training happens over a fixed period of time, each of the stakeholder organizations does not need to be online at the same time.
- A given disaster scenario is picked within area of the Web environment such that all stakeholders refer to the same data. Stakeholder organizations access the Web environment to study the particular earthquake scenario data in this area of the Web site, afterward sorting the corresponding disaster-planning issues within the Web.
- Each stakeholder organization ranks importance of issues, orders necessary actions in time sequences, requests resources, and generally responds to the disaster. The information given by each stakeholder organization will, at the end of the fixed time period, interact with the information given by other stakeholders through voting, summation, and other means.
- Resulting potential conflicts will be picked up by the Web system and clearly expressed in terms of resource bottlenecks and priorities. Areas of consensus also will emerge. It will be possible to see directly which stakeholders are competing for a given limited resource (e.g., helicopters, road access, power) and which stakeholders are in agreement about the issues.
- To resolve potential conflicts, knowledge about why and who is in the conflict is necessary. "Who" is readily accessible, as the system points to each party that is in conflict over resources or philosophy. "Why" is recoverable through stakeholder information about competing missions and modes of operation available in the Web environment.

As a greater "system" understanding emerges among individual stakeholder organizations and members, they can refine their emergency planning and solutions. This Web consensus-building and decision-support environment is not proposed as a substitute for the existing means of communication between the involved stakeholders, but rather should be viewed as a supplementing tool that can facilitate mutual understanding of different organizations' needs, resulting in better disaster preparedness.

Concluding Remarks

The Los Alamos Urban Security team has been charged with developing an approach to urban modeling from a multidisciplinary scientific perspective. Over a period of less than 2 years, this interdisciplinary team and its collaborators have made strong steps toward developing tools to better understand the integrated urban systems. This view of cities is mandatory if we are to anticipate and mitigate the vulnerabilities that will affect our security and quality of life. Our approach has focused on simulation science and the modern computing platforms that are required to develop these systems. A key part of the initiative is to involve the planning and policy communities to help focus the science.

Notes

1. The manner in which processes affect each other where the effects of one process on another results in an effect on the first is a feedback mechanism. For example, automobile traffic results in hot spots of air pollution during commuting hours. Traffic controllers then redirect some traffic to reduce pollution in the hot spots. In this manner, the air quality, initially affected by traffic, in turn determines the traffic. When processes affect each other through feedback mechanisms, the changes in each process in general do not follow linear trends (hence, they are nonlinear).

2. Implementation of the mathematical description of a process on a computer. If the mathematical description (set of equations) is complete and accurate, the solution of the equations produces a model of the real system.

3. Synthetic population modeling is a method of creating an artificial group of people that statistically mimics a real group of people. For example, simulation of commuting habits of individuals, for input into an urban transportation simulation, uses a synthetic population rather than the habits of actual individuals. Because the statistics are correct, the large-scale behavior of the simulated system mimics the real one.

4. A computer-based method for storing, analyzing, and visualizing data that are spatially organized (e.g., such information on a map).

5. A programming language that is object oriented, distributed, and architecture neutral. A JAVA program written on one hardware platform may be run on any platform that provides a JAVA virtual machine. JAVA includes networking capabilities and file transfer protocols.

6. CORBA = common object request broker architecture. It defines the standard specifying how distributed objects interoperate in a heterogeneous environment. CORBA IDL (interface definition language) is used to specify an object's interface and allows objects written in different languages to interoperate across distributed networks and diverse operating systems. CORBA may be viewed as a software bus into which any CORBA-compliant object may be plugged.

7. TRANSIMS = transportation simulation system. A Los Alamos–developed modeling system that computes traffic flow based on hundreds of thousands of interactions of individual travelers on the road network.

8. HOTMAC = higher order turbulence model for atmospheric circulation. A computer code developed at Los Alamos that predicts three-dimensional time-varying wind, temperature, moisture, and turbulence fields over mountains and valleys, cities, coastal regions, and so on. The code uses conservation equations for mass, momentum, energy, and moisture that are used to predict how the meteorological fields will change (Williams & Yamada, 1990).

9. GASFLOW is a computer program developed at Los Alamos that predicts the three-dimensional time-varying flow fields around buildings and other obstacles. It uses mathematical routines optimized for the computer to solve conservation equations for mass, momentum, and energy (Travis, Lam, & Wilson, 1994).

10. A spatial structure where the dynamics in each point is determined by the state of the given point and the state of a set of other points in some neighborhood around this point.

11. Chemicals in the air that react to form nitrate compounds.

12. RAMS = regional atmospheric modeling system (Pielke et al., 1992). A computer code that predicts how winds, temperature, moisture, clouds, and rain will change with time and space. RAMS is typically used to simulate these meteorological fields over regions the size of the United States or a few states and can zoom in on a smaller region of interest (such as the Los Angeles Basin).

13. SWMM = storm water management model. An EPA-sponsored code that routes water over urban catchments and through storm channels and pipes. It also computes the transport of different water pollutants throughout the system (Huber & Dickinson, 1988).

14. WASP = Water Quality Analysis and Simulation Program. A code developed for understanding transport, chemistry, and biological processes and interactions in bodies of water.

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